FINAL TECHNICAL REPORT

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GEOTECHNICAL ARRAY DATA ANALYSIS AT THE HOLLISTER EARTHQUAKE
OBSERVATORY AND NEES/ANSS INTEGRATION

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Title: Geotechnical Array data analysis at the Hollister Earthquake Observatory and NEES/ANSS integration

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ABSTRACT:

A significant component of the research efforts at the Institute for crustal studies (ICS) are centered around understanding the physics of the earthquake process and the effects of earthquakes on the built environment. These require not only computational facilities for doing theoretical modeling of wave propagation and earthquake source process simulation, but also field observatories for monitoring earthquake activity. These field observatories provide the control data for testing our theoretical models and simulation techniques, so we can determine if our models are matching real observations of earthquakes. One of these field observatories is the Hollister Earthquake Observatory (HEO), located in the northwest corner of the Salinas Valley, CA. This observatory, donated to ICS by the Japanese firm Kajima Engineering and Construction Corp., is now integrated into the National Science Foundations George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES) program, through the multi-agency collaboration with the US Geological Survey, facilitated by this NEHRP external program award.

Figure 1. Map showing the location of the Hollister Earthquake Observatory

In the spring of 2007 through funding under this USGS program, the HEO site was upgraded with a Kinemetrics, Inc. Marmot field processor and VPN network router that allowed the site to be integrated into the NEES@UCSB data acquisition and processing infrastructure. Continuous data from the HEO site now flow in real-time to UCSB and is archived. In addition, routine processing which segments out events from the continuous data stream for the NEES field sites is also now set up for the HEO station. Automated data analysis of each event waveform provides peak acceleration, peak velocity, and signal to noise ratios for each record. Through the NEES@UCSB program, we have also been developing web-based applications for state-of-health monitoring and data dissemination tools for all the instrumented geotechnical field sites. The HEO site has now been integrated into these online processing and analysis tools.

Background: The Hollister Earthquake Observatory

Agbabian Associates installed the Hollister Earthquake Observatory (HEO) in 1991 with funding from the Kajima Engineering and Construction Corp. Kajima Corp donated this array to the University of California, Santa Barbara in January 1998. It is located in the Salinas Valley where alluvium overlies Tertiary sandstone overlying granitic basement (Figures 2). HEO has been operating since early 1992, and is located approximately 10 kilometers from the San Andreas Fault near the cities of Hollister and Salinas in central California. The ground motion array consists of a vertical array of six accelerometers at the main station located on Quaternary alluvium, and three accelerometers installed at a remote rock station, 3 km to the Northeast (Figure 1). At the HEO main station accelerometers are located at 192, 110, 50, 20, 10, and 0 meters depth, going from crystalline rock at the bottom, up through consolidated and unconsolidated alluvium to the surface (Figure 2). Three sensor locations, surface Sandstone, surface Granite, and GL-53 meter borehole Granite are instrumented at the remote rock station. Measured velocity profiles at both the main soil station and the remote rock station are shown in Figure 3. The location of HEO along the San Andreas Fault in Central/Northern California makes it an important addition to the engineering seismology test sites operating in California and the United States.
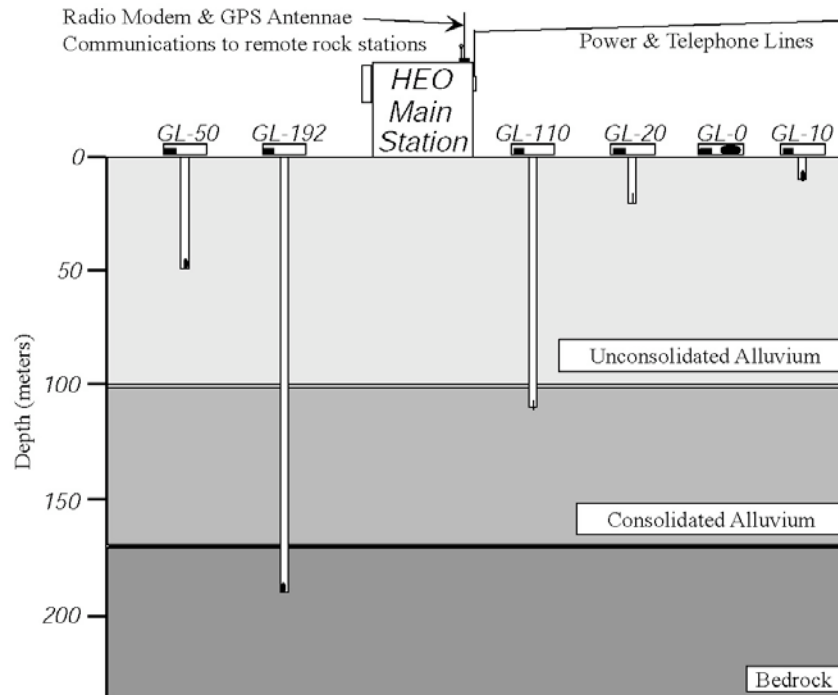

Figure 2. HEO main station soil cross-section and borehole instrument layout.

As an example of the type of data being recorded at the HEO site, an M5.1 earthquake that occurred 13 km almost due east of HEO and the acceleration time histories for the 180° horizontal component are shown in Figure 4. The largest peak acceleration occurs on the granite outcrop. Note the similarity between the two borehole recordings in rock: GL-192m and Gl-53m. Notice the difference between the two outcrop observations at the remote site

(Tertiary and granite), both which might be classified as rock in many attenuation models and used as the rock input motion for driving a nearby soil column. The Tertiary and granite recordings are located approximately 325 meters apart, while the GL-53 and GL-192 recordings are an order of magnitude further, 3km apart, yet are a much more consistent and a better representation of the true seismic input. Even while remaining in the linear strain regime (<0.1g), these records still emphasize the importance of vertical array data. The main station recording building and the remote station recording hut are shown in Figure 1. This infrastructure represents a significant investment in engineering seismology that is now made available to the researchers and the public thanks to the NEES and ANSS/USGS programs.
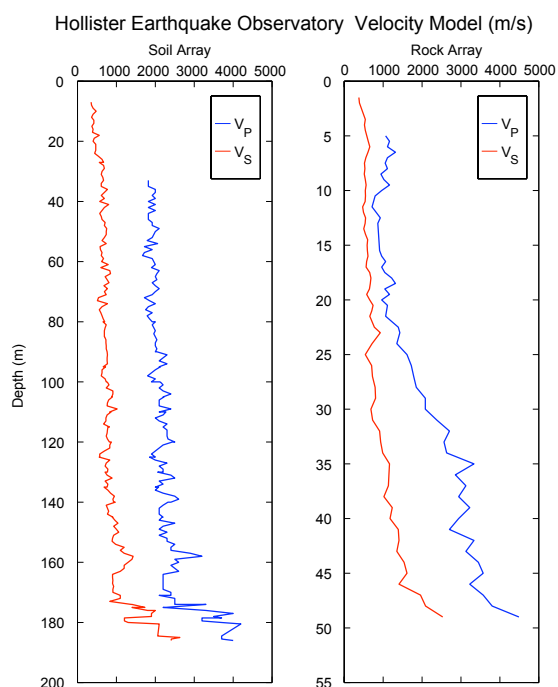

Figure 3. Measured velocity profiles from the HEO main soil station and remote rock station.
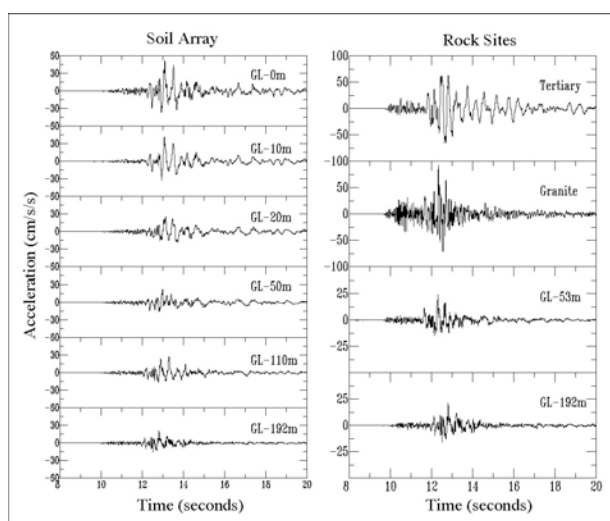

Figure 4. Acceleration time history for M5.1 mainshock recorded at HEO. Note the scale on left and right side is different. The main station GL-192 record is repeated on the right for direct comparison with remote rock site GL-53 record both plotted at the same scale.

Project Deliverables and Results:

A primary focus of this project was to upgrade the HEO field site and integrate it into the acquisition, processing, analysis, and data dissemination tools that are part of the NEES permanently instrumented field site program at UCSB. The upgrade included the deployment of a Kinemetrics Marmot field processor, running Linux and the Antelope software that enables the local buffering of continuous data, and real-time streaming of data back to UCSB. Figure 5 shows the installed Marmot field processor at HEO.

Figure 5. Kinemetrics Marmot Field Processor installed at HEO.

The addition of the Marmot field processor at HEO allows for buffering of about 7 days of continuous data on solid-state flash. Any telemetry outage less than 7 days is automatically recovered from with no human intervention as part of the normal operations using the Antelope software package. In addition to the buffer provided by the Marmot, a daily cron job runs on the Marmot that automatically connects to a network attached storage device (NAS), and copies the contents of the data buffer from the previous day onto the NAS hard drive. This drive has the capacity to hold over a full year of continuous data.

One advantage to having real-rime communications and data delivery is the ability to monitor the state of health of data acquisition equipment at the site, and the functionality of the sensors. The ability to have a continuous record of temperatures and being able to monitor the power at the site is important (Figure 6).

Data processing developments made possible through the NEES@UCSB program provide web-based access to state-of-health information about each of the permanently instrumented field sites. Figure 6 is an example of the temperature, power supply voltage, and current usage at the HEO site for a 1-month period as recorded by the data acquisition system. This web-based interface allows users to access information at a variety of time scales including hourly, daily, weekly, monthly, yearly, or lifetime of the station. The HEO remote rock station is operated exclusively on solar power, with large batteries for backup. Having the ability to monitor the operational voltage during the stormy winter months lets UCSB personnel keep an eye on things 24/7 from any computer with a network connection (Figure 6). The backup batteries last through storms that last for many days, but multiple storms in a row could potentially cause the low voltage disconnect to kick in. We have not observed this since installing new batteries two winters ago, however, if/when this does happen, it is an indication that it's time to change the batteries. Typically a single day of sunshine is enough to top the batteries off again.
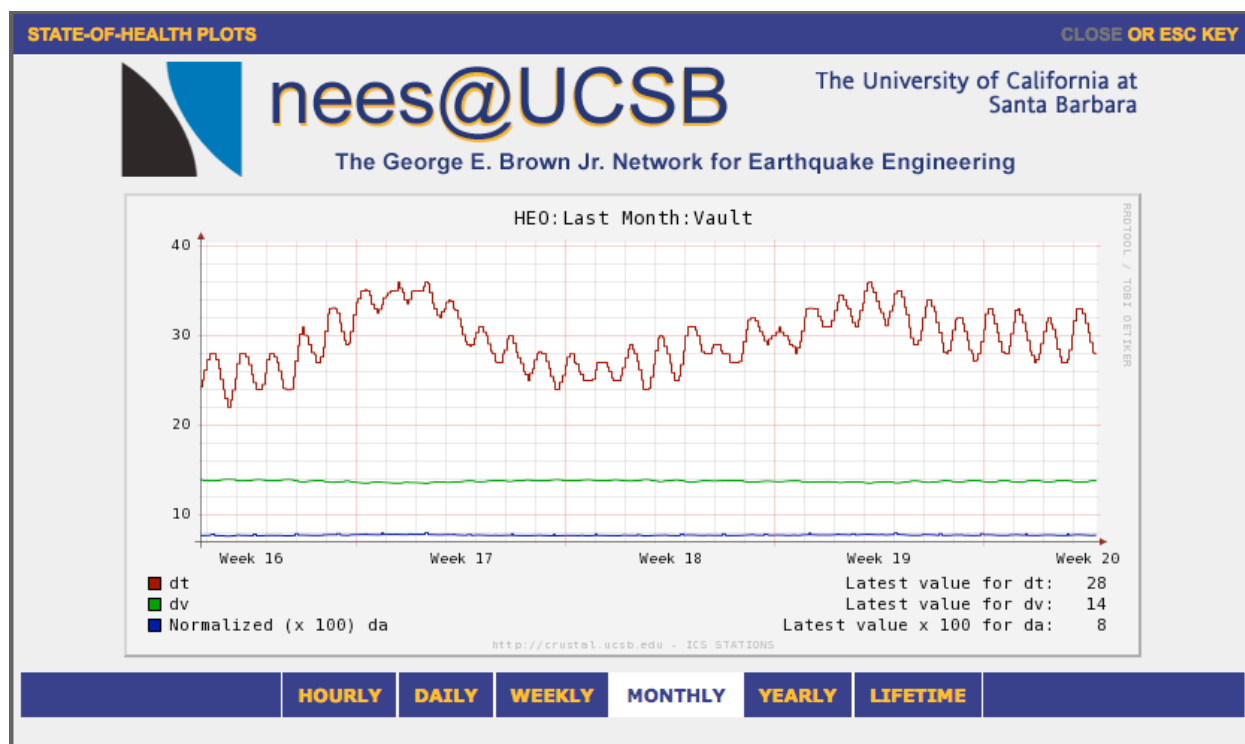
Figure 6. Screenshot showing the incorporation of the HEO site into the NEES@UCSB web-based site monitoring tools. Station state-of-health parameters such as power and temperature are provided through a web-accessible interface.
[http://nees.ucsb.edu/facilities/dlmon]

The ability to observe waveforms from any of the sensors in real-time provides us with a constant functionality check on the status of the sensors. A real-time 24-hour display of all sensor channels back at UCSB lets us quickly know if there are problems with a datalogger, sensor, or individual component.

The routine processing and analysis of data from the NEES@UCSB field sites includes the segmenting out the earthquake waveforms from the continuous data using a distance scale based on magnitude range. Small events are segmented out only when they occur close to the site, as the events get further from the site, a larger magnitude is required before the event will qualify to be segmented out of the continuous database. We use the ANSS catalog of earthquakes (which includes regional network determined magnitudes and locations) in this process of creating the segmented event waveform database. The HEO site is now included in this routine data processing that was developed under the NEES program.

In addition to the automated segmenting of waveforms from the HEO site, events are examined periodically to ensure functionality of the sensors. The event data is stored in an online database at UCSB using a RAID storage system that allows for instant access to these records. Figure 7 is an example of an M4.2 event recorded at ~12km from the HEO site. The accelerometers at HEO are a combination of older FBA23 and a more recent MEMS technology accelerometer, and are capable of recording earthquakes as small as M2.0-3.0

depending on proximity and sensor type, all the way up to +/- 3g accelerations from large sources in the near field.

A combination of dataloggers is used at the HEO site, with some of the sensors connected to a 12-channel Kinemetrics K2 system, and some sensors connected to Quanterra Q330 systems. The K2 operates in triggered mode only, while the Q330 sends data back to UCSB in real-time. The surface and deepest (GL-192m) sensor at the main station and all three sensors at the remote site are connected to the Q330 data logger. Figure 7 shows an example of the data with PGA of just below 0.1%g (10 gals), below the trigger threshold of the K2. Should ground accelerations exceed the K2 trigger threshold, these records are automatically integrated into the real-time data stream and transmitted back to UCSB where they are processed in the same way as the continuous data and placed in the event waveform database.
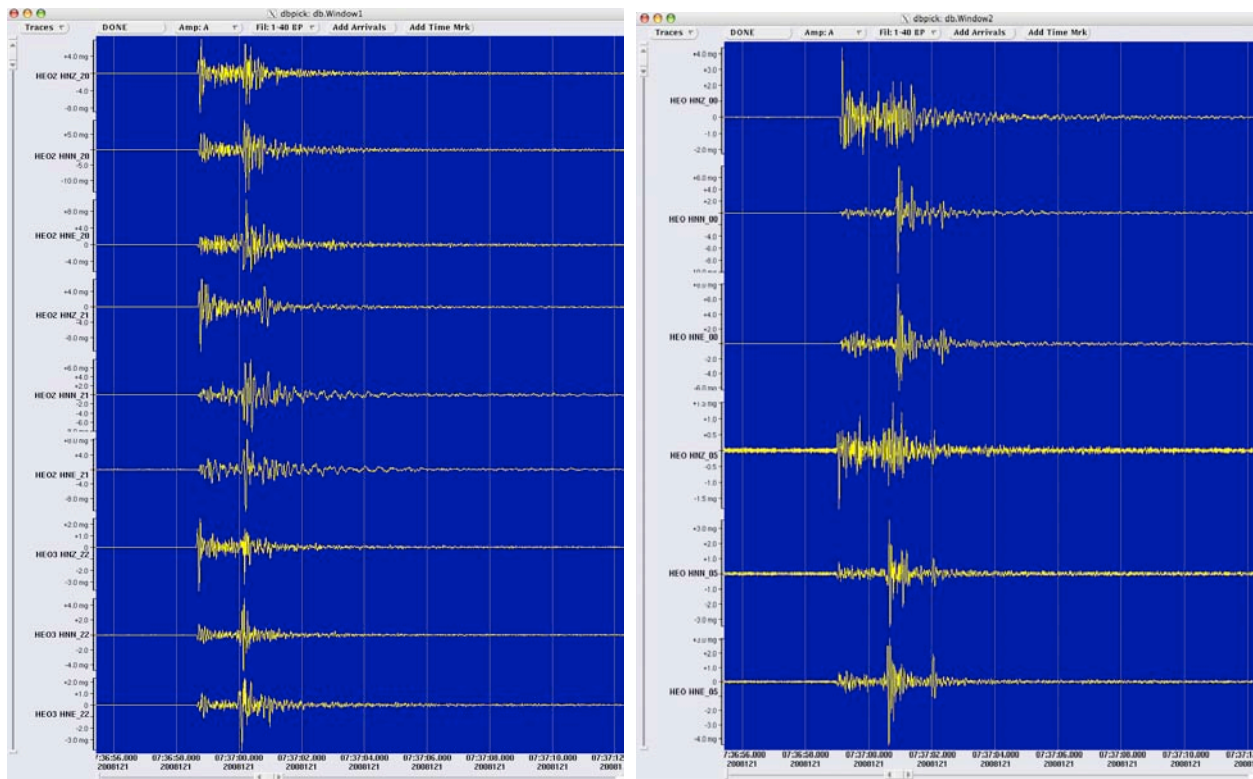

Figure 7. HEO Vertical Array 3-component recordings of a M4.2 at ~10km distance. Left panel shows accelerations from the granite (top), Tertiary (middle), and GL-53m borehole sensors at the remote rock site. Right panel shows accelerations from the surface and GL-192m borehole sensor at the main station.

One of the goals of the NEES@UCSB facility is to improve data dissemination from geotechnical array sites. Over the last few years, a web-based dissemination tool has been developed to help increase the number of researchers using this data. The idea is to make the segmented event database searchable, and the waveforms accessible, via an online data portal. This process is now almost completed, though development continues as we get

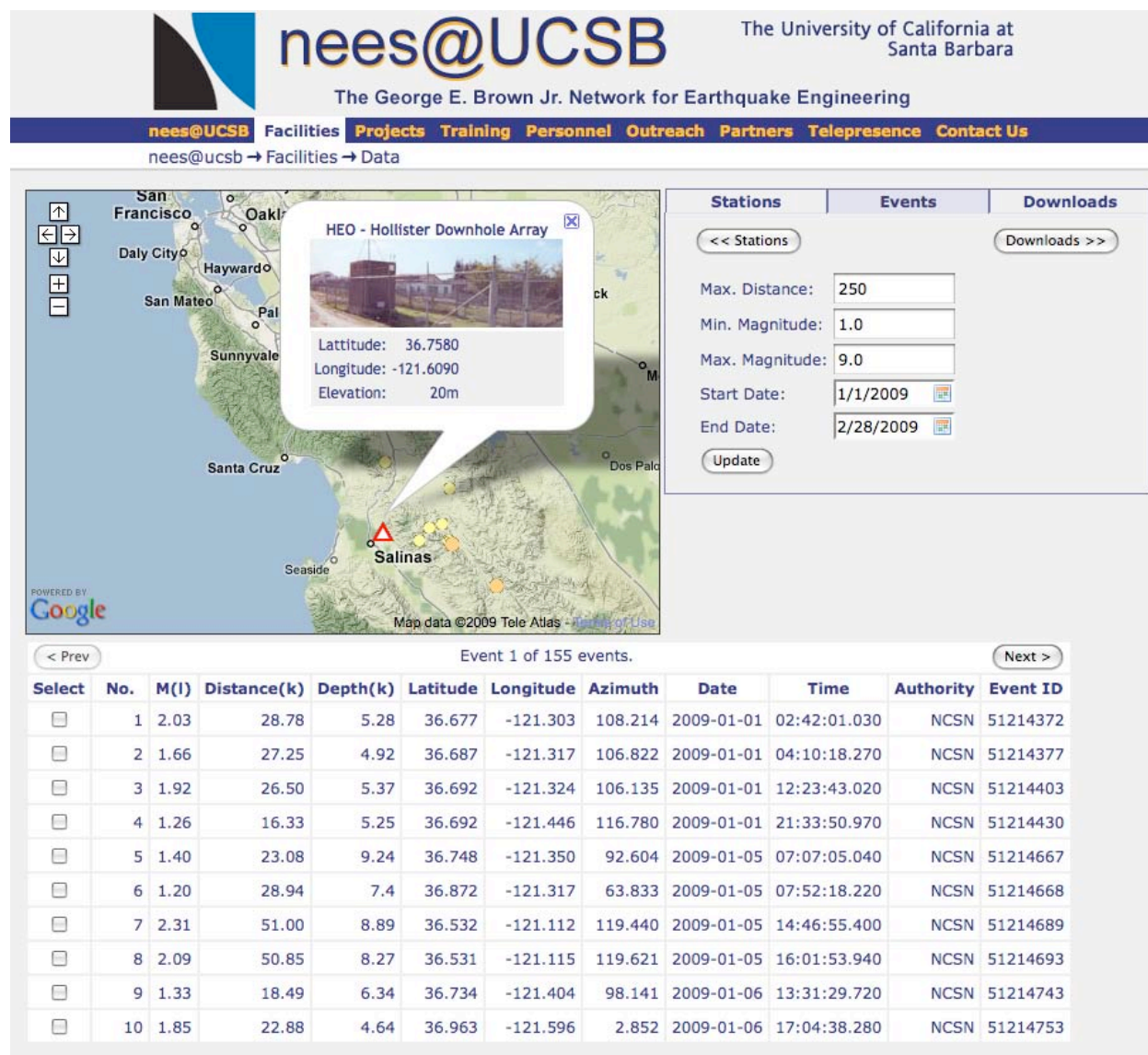feedback from users. The HEO data has been integrated into this data dissemination tool as shown in Figure 9.

Figure 9. Screenshot showing the incorporation of the HEO site into the NEES@UCSB web-based data dissemination tools.

From the NEES@UCSB website, the search interface currently provides the ability to select a station from a Google Map interface or drop down menu. The available channels are then shown for the particular station, with the ability to select individual channels, or all channels. The Event tab will then provide the ability to search for available events based on magnitude, distance, and time period. The event search returns a list of events with the events also shown on the Google Map interface (Figure 9). After selecting the event, the user can then download individual waveform files, or package a group of files, with the

ability to continue to add packages for other events, before downloading all selected packages.

Currently, data is provided in three formats, miniSEED, ASCII (for Excel or MATLAB), and RDV (a variation of ASCII that is meant for the NEES Java based real-time data viewer tool). The miniSEED format is provided in raw counts and is for more advanced users. The ASCII data formats can be provided with calibration applied to physical units, or in raw units by the user. Making other data formats available for dissemination, for example SAC, is under consideration and will depend on user feedback. Tracking mechanisms for the number of waveforms downloaded and the number of users will also be available. Search capabilities using signal-to-noise ratios, peak acceleration, and peak velocity are currently under development. Lastly, the ability to view waveforms and zoom in and out through the web browser are currently under development in a collaboration between the EarthScope Array Network Facility and the NEES program. This web-based waveform viewer should be available in summer 2009. The HEO data will be incorporated into these developments.

Conclusions and Future Work:

The project has been successful from the standpoint of the integration of the HEO field site with the NEES program. The primary goal of installing the Marmot field processor and establishing a link to the automated processing tools developed under the NEES program has been accomplished. Beyond this, the data dissemination tools and all other future NEES software development work will also be directly applicable to the HEO field site. Future work is planned to integrate the HEO field site event database into the MATLAB analysis tools currently under development. This will provide the ability to easily access the event waveform database and perform vertical array seismogram inversions to examine attenuation and site response analysis in the low-strain regime, and eventually the large-strain regime when the Earth decides to cooperate.

Publications:

The general data dissemination tool development has been reported at the 14th World Conference on Earthquake Engineering, and while the BVDA site was not specifically mentioned in this publication, the development tools apply to BVDA as well as the other NEES and non-NEES sites.

Steidl, J. H., R. L. Nigbor, T. L. Youd (2008). Observations of *insitu* soil behavior and soil-foundation-structure interaction at the George E. Brown, Jr. network for earthquake engineering simulation (NEES) permanently instrumented field sites, *Proceedings of the 14th World Conference on Earthquake Engineering, October 12-17, 2008 Beijing, China*, paper S16-01-014.

Once the web-based waveform viewer and event search tools are completed, we plan to submit a Seismological Research Letters manuscript to help publicize the data availability and web-based dissemination tools.

The waveform analysis and seismogram inversion results are still a work in progress. We have been porting the inversion code over to MATLAB so that we can take advantage of the Antelope waveform database interface to MATLAB. This will allow easier and more automated processing and analysis of events in the online waveform database. A paper is in progress related to the site response and attenuation effects at the BVDA site, as well as other geotechnical array sites for publication in Soil Dynamics and Earthquake Engineering or the Bulletin of the Seismological Society of America. . Funding under this program will be acknowledged when this paper is published, and a copy will be provided.